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On the analysis of received signal strength indicator from ESP8266

Rafhanah Shazwani Rosli, Mohamed Hadi Habaebi, Md Rafiqul Islam
Department of Electrical and Computer Engineering, International Islamic University Malaysia, Malaysia

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ABSTRACT

Recently, the concept o Internet of Things has gained a tremendous momentum in the technological world. Internet of Things efficiency connects devices hence improving their quality of life from various aspects. One of the most heavily used device for Internet of Things application is ESP8266 WiFi serial transceiver module. It features access to the Received Signal Strength Indicator readings from the module. In this paper, a characteristic analysis of the Received Signal Strength Indicator readings collected using ESP8266 WiFi serial transceiver module is carried out. The aim is to explore the future possibilities of Received Signal Strength Indicator value as a stand-alone and unique parameter to be used in various applications especially in the domain of Internet of Things. In addition, the potential of the cheap yet sophisticated ESP8266 WiFi serial transceiver module is also highlighted. The findings have shown an insight into the characteristics of Received Signal Strength Indicator readings and how it can be utilized for other different purposes. The findings have brought up a few stimulating issues that may arise from some implementation of Received Signal Strength Indicator readings such as the significant effect of obstruction in the Line of Sight. However, its solution will thrust the Internet of Things' technological advancementsahead.

Corresponding Author:

Rafhanah Shazwani Rosli,
Department of Electrical and Computer Engineering,
International Islamic University Malaysia,
Jalan Gombak, 53100, Kuala Lumpur, Malaysia.
Email: rafhanah.shazwani@gmail.com

1. INTRODUCTION

Received Signal Strength Indicator (RSSI) is a parameter widely known in the area of wireless networking environment. RSSI of an IEEE 802.11 system is the approximate strength of received signal in arbitrary units. The value of RSSI can be obtained from the processing of voltage changes as measured by the receiver's circuit [1]. However, reading of RSSI is not related to any standard physical parameter as defined by 802.11 standards. The readings of RSSI are correlated with the distance between the transmitter and receiver. There are several factors that may affect the RSSI value perceived by the receiver. Some of the factors are reflection, diffraction, signal source and also obstruction in the path of the radio signal wave.

WiFi serial transceiver module discussed in this paper is ESP8266 WiFi serial transceiver module. It is a self-contained system on chip integrated with TCP/IP protocol stackthat would allow access to WiFi, WiFi direct Peer-to-Peer (P2P) and soft Access Point (AP) mode.It supports APSD for VoIP application and also Bluetooth co-existence interfaces. ESP8266 is also equipped with a self-calibrated RF. This feature allows it to work under all operating conditions and requires no external RF parts [2]. There are various models of ESP8266 WiFi serial transceiver module. The most basic and general version, which is ESP8266-01 is sufficient to be used for the analysis in this paper. Figure 1 shows the ESP8266-01 model with its pins distribution and size measurement. Through its general-purpose input/output (GPIO) pins, the module is able to be integrated with sensors or any other application specific devices. It has an onboard processing and storage capability enabling it to be integrated with sensors or many other devices for Internet of Things application.

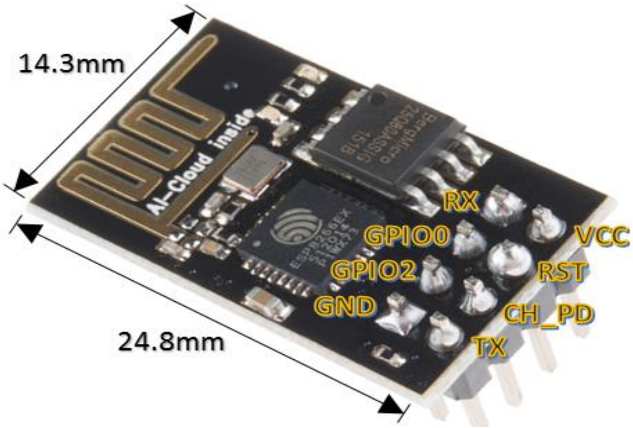

Figure 1. ESP8266-01 pins distribution and size measurement

RSSI has been discussed in numerous researches. The method to process RSSI values and implement it for various Internet of Things applications has become an interest to many researchers. Recent studies have introduced new and innovative usage of RSSI for human position estimation method. The implementation can be applied as an imperative function for secure and safe services and energy efficiency of small areas. However, a research shows 25% decline in performance when the experiment was conducted in different locations such as laboratory and library [3]. The entropy of information extracted from RSSI samples sequence can be applied in human presence detection method as presented in [4]. RSSI variations at the receiver's input of radio transceivers vicinity may be caused by the presence of a human. Therefore, by quantifying and analyzing irregularities in the radio signature, human presence in an indoor environment can be recognized. Furthermore, RSSI can be utilized in localization. For example, a pedestrian monitoring system using WiFi technology is presented in [5]. RSSI is employed from multiple anchor nodes from an operating wireless sensor network in the proposed system in [6] to track indoor pedestrian with on-body multiple receivers.

Hence, the objective of this paper is to analyze the characteristic of RSSI readings collected using ESP8266 WiFi serial transceiver module. Consequently, portraying the future possibilities of RSSI to be used in different applications and implementations. This paper features an extensive work, as demonstrated in [7]. This paper is also correlated to the work in [8]. The organization of this paper is in the following manner. Section 1 is the Introduction that briefly explains the general background of RSSI and the WiFi serial transceiver module, related researches and the aim of this paper are also discussed. Section 2 presents the method used to analyze the characteristic of RSSI from ESP8266 WiFi serial transceiver module. Section 3 presents the results obtained from experimentations along with its discussion. Section 4 concludes the paper. Lastly, acknowledgment, references and biographies of authors are included in the last three sections.

2. RESEARCH METHOD

The characteristic of RSSI readings collected using ESP8266 WiFi serial transceiver module is analyzed from two aspects. The first aspect is on how obstruction in the Line of Sight (LoS) of RSSI affects the RSSI readings. The second aspect is on how sampling rate and human crossing at the LoS of RSSI affect the RSSI readings. Both aspects are investigated under different experimental setups. The ESP8266 WiFi serial transceiver module is programmed with the algorithm to behave as either transmitter or receiver. The transmitter ESP8266 is programmed to act as an access point that has a unique SSID and password. The receiver ESP8266 is programmed to connect to the WiFi Protected Access 2 (WPA2) network of the transmitter ESP8266 and read its RSSI value.

The first experiment is to investigate the effect of obstruction to RSSI readings. Obstruction in this experiment is defined as the physical matter that impedes the direct free-space path or Line of Sight (LoS) between the ESP8266 transmitter and receiver. Figure 2 shows the experimental setup to investigate the effect of obstruction to RSSI readings.

The experiment takes place in an office room where the transmitter is positioned on the desk 1metre off the ground. The distance between the transmitter and receivers is 1metre. Receiver 1 is positioned on the same level as the transmitter and is used to observe RSSI value of unobstructed LoS. Receiver 2 is also positioned on the same level as the transmitter but outside of the closed office room to observe the RSSI value of obstructed LoS. An overt physical obstruction between the transmitter and receiver 2 is a brick wall with 75mm thickness.

The second experiment is to investigate the effect of sampling rate and human crossing to RSSI readings. Sampling rate is the number of RSSI reading taken by the receiver per second. The sampling rate is programmed by inserting a time delay in the receiver's algorithm loop. In this experiment, the time delays observed are in the interval of 100ms and start with 5ms as it is the closest possible delay to 0ms. The time delay is then converted to sampling rate using (1).

$$\text{Sampling Rate}=\frac{1}{\text{Time Delay}} \tag{1}$$

Figure 3 shows the experimental setup to investigate the effect of sampling rate and human crossing to RSSI readings. The transmitter and receiver are positioned 1metre apart from each other and 1metre above the ground. They are located in between a door opening to let a human subject cross the LoS between the transmitter and receiver. The same human subject is used throughout the experiment.

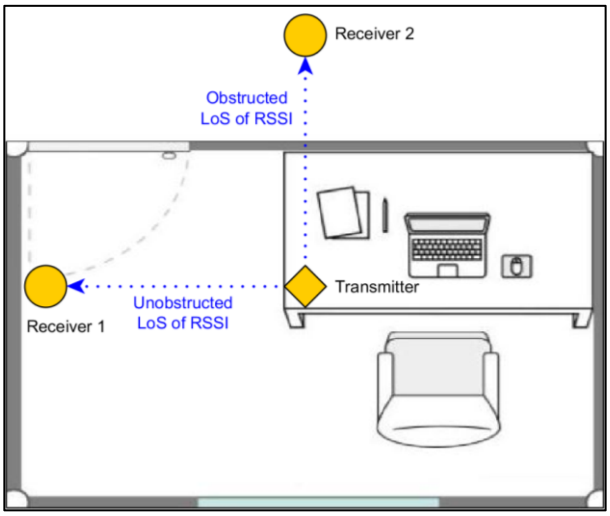

Figure 2. Experimental setup to investigate the effect of obstruction to received signal strength indicator readings [7]

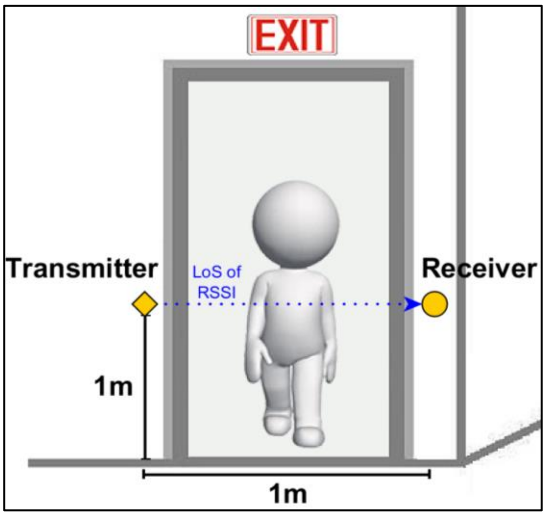

Figure 3. Experimental setup to investigate the effect of sampling rate and human crossing to received signal strength indicator readings [7]

3. RESULTS AND ANALYSIS

The two experiments as explained in Section 2 are conducted. The resulting graphs and data are presented in this section.

3.1. The effect of obstruction in the line of sight

To observe the effect of obstruction in the LoS, two samples of 1000 RSSI readings are obtained with the sampling rate of 10Hz from receiver 1 and receiver 2. Receiver 1 samples unobstructed RSSI readings and receiver 2 samples obstructed RSSI readings. The result of the first experiment is as shown in the graph of Figure 4. The minimum value, maximum value, mean and standard deviation of the two RSSI readings samples obtained from the first experiment are calculated and tabulated in Table 1.

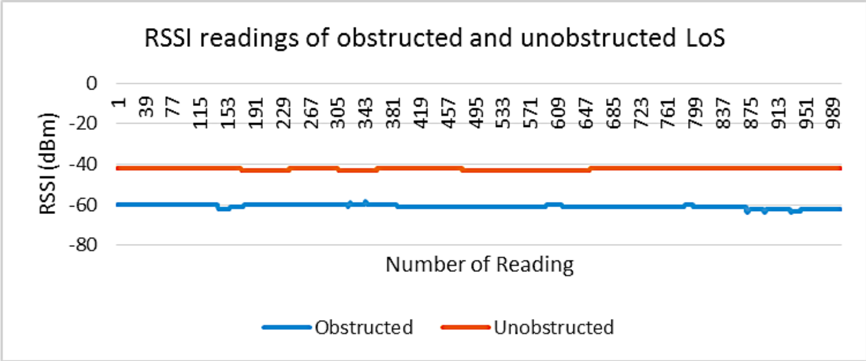

Figure 4. Received signal strength indicator readings for obstructed and unobstructed line of sight

Table 1. Descriptive statistics of received signal strength indicator samples from obstructed and unobstructed line of sight

LoS	*Min (dBm)*	*Max (dBm)*	*Mean (dBm)*	*Standard Deviation*
Obstructed	-61	-58	-60	0.55
Unobstructed	-43	-42	-42	0.45

There are conspicuous differences between the statistics of the obstructed and unobstructed samples. The minimum RSSI value of obstructed sample is -61dBm and for unobstructed sample is -43dBm. The maximum RSSI value of obstructed sample is -58dBm and for unobstructed sample is -42dBm. The average RSSI value of obstructed sample is -60dBm and for unobstructed sample is -42dBm. The standard deviation of obstructed RSSI sample is 0.55 and for unobstructed RSSI sample is 0.45.

There are concerning effects that can be observed from the statistics. Obstruction causes the strength of the received signal to significantly reduce. Comparing to the mean of unobstructed RSSI sample, the mean of obstructed RSSI sample is 30% less. The standard deviation of obstructed RSSI sample is 22.22% higher than the standard deviation of unobstructed RSSI sample which means that the RSSI readings fluctuate more due to obstruction. In another perspective, RSSI can be described in relation to distance from the Log-Distance path loss model in (2) [9].

$$\mathrm{RSSI}=-10n\log_{10}\left(\frac{d}{d_0}\right)+A_0 \tag{2}$$

where;

n=Signal propagation exponent
d=Distance between transmitter and receiver
A_0=Referenced RSSI value at d_0

The RSSI readings from obstructed RSSI sample can be validated by computing the value of using (2). Let n=2 which is the signal propagation exponent for indoor settings [10]. The distance between receiver 1 and the transmitter is d_0=1m. The mean of unobstructed RSSI sample is considered as the referenced value of RSSI at d_0, A_0=-42. The value of d is obtained by substituting the mean of obstructed RSSI sample into (2). The solution is as follows:

$$(-60)=-10(2)\log_{10}(d/(1))+(-42)$$
$$-18=-20\log_{10} d$$
$$0.9=\log_{10} d$$
$$d=10^{0.9}$$
$$d=7.94\text{ m}$$

Based on the value obtained from the solution above, the distance between receiver 2 and the transmitter is 7.94m. The % error of the distance measurement is then calculated using (3).

$$\%\ \mathrm{Error}=\left|\frac{(\text{Known Value}-\text{Obtained Value})}{\text{Known Value}}\right|\times 100 \tag{3}$$

$$\% \text{ Error} = \left|\frac{(1-7.94)}{1}\right| \times 100 = 694$$

An obstruction of a brick wall with 75mm thickness causes 694% of error to RSSI readings. Such colossal error is a big hindrance especially if RSSI is to be used in distance-related implementation. It is also safe to assume that different material with different thickness will produce a variation of % error. This assumption is supported by the Shapiro-Wilks tests for obstructions in [11].

3.2. The effect of sampling rate and human crossing

To observe the effect of sampling rate and human crossing, six samples of RSSI readings are obtained. Each sample of RSSI readings is taken with different sampling rate during crossing and non-crossing. The resulting graphs of RSSI readings are shown in Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, and Figure 10 which are taken at sampling rate of 2Hz, 2.5Hz, 3.33Hz, 5Hz, 10Hz and 200Hz respectively.

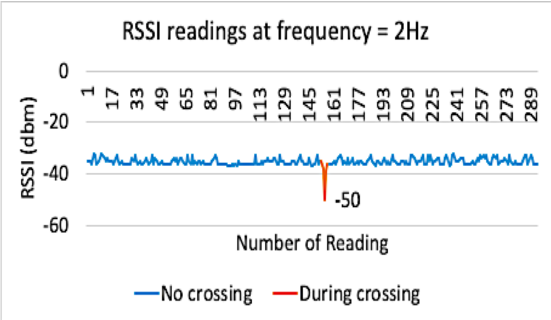

Figure 5. RSSI readings at sampling rate of 2Hz

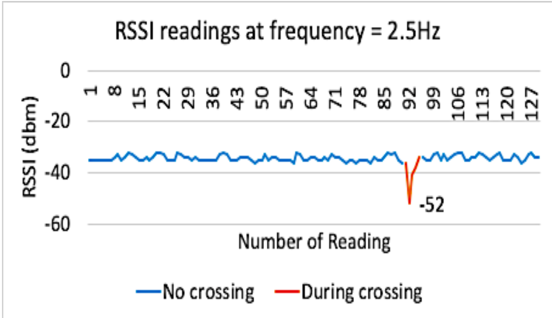

Figure 6. RSSI readings at sampling rate of 2.5Hz

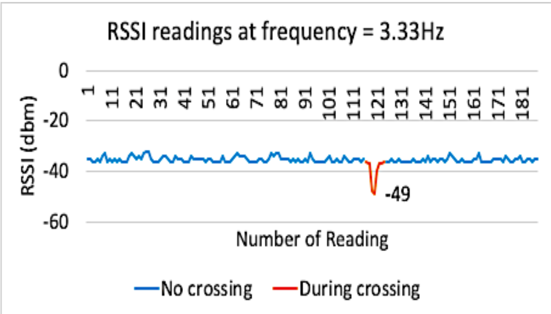

Figure 7. RSSI readings at sampling rate of 3.33Hz

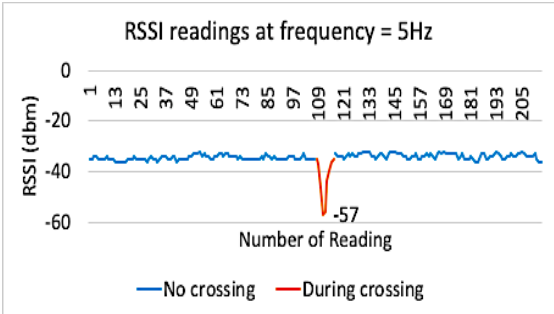

Figure 8. RSSI readings at sampling rate of 5Hz

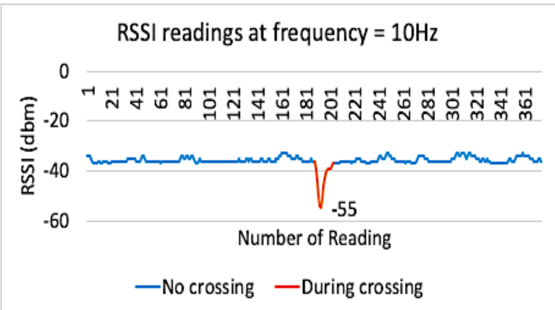

Figure 9. RSSI readings at sampling rate of 10Hz

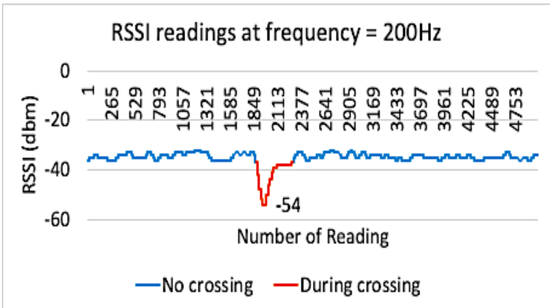

Figure 10. RSSI readings at sampling rate of 200Hz

From the graphs, it can be observed that the RSSI readings are noisy during no crossing of human subject. During crossing, as the human subject enter the LoS, the value of RSSI readings dropped significantly to a negative peak and rise back as the human subject leave the LoS. Crossing of human subject causes the RSSI readings to drop as propagation signal is attenuated due to shadowing effect at the path of LoS [12].

The descriptive statistics of datasets for all six sampling rates are calculated and tabulated in Table 2. The parameters observed during no crossing of human subject is the minimum value, maximum value, mean and standard deviation of RSSI readings samples. The parameter observed during crossing of human subject is the negative peak or the minimum value of RSSI readings in the sample taken during crossing.

Table 2. Descriptive statistics of received signal strength indicator samples fromvarious sampling rate and human crossing scenario

Sampling Rate (Hz)	No crossing *Min (dBm)*	*Max (dBm)*	*Mean (dBm)*	*Standard Deviation*	During crossing *Negative Peak (dBm)*
2	-37	-32	-35	1.10	-50
2.5	-36	-32	-34	1.11	-52
3.33	-36	-32	-35	0.93	-49
5	-36	-32	-34	1.01	-57
10	-37	-33	-35	0.85	-55
200	-37	-32	-35	1.05	-54

From the values in Table 2, it can be observed that there are no significant differences in the minimum and maximum values between all the samples of different sampling rate. This is because all samples are taken at the same experimental setup and no obstruction is present at the LoS. There are slight differences in the resulting standard deviation values as portrayed in a graph shown in Figure 11.

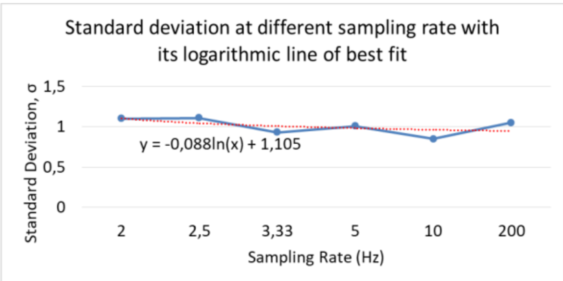

Figure 11. Standard deviation at diferent sampling rates

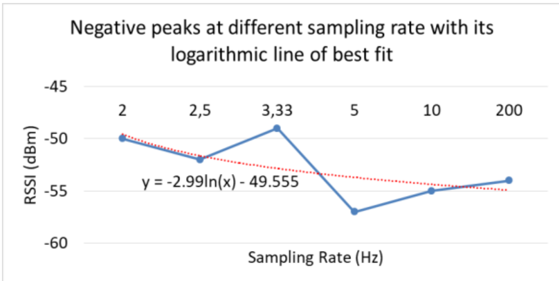

Figure 12. Graph of negative peaks at different sampling rates

Standard deviation is an important parameter to observe the fluctuation of RSSI readings which may bring insights to the signal noises. From the values of standard deviation between the six sampling rates, it can be observed that the relationship of sampling rate and standard deviation is indirectly proportional. A logarithmic line of best fit is computed where y is the standard deviation and x is sampling rate. If a different sampling rate is to be used, the standard deviation would not deviate much from the line of best fit. Hence, RSSI reading is not affected significantly by sampling rate. The value of negative peaks obtained during the crossing of a human subject at different sampling rates is as shown in the graph of Figure 12. A logarithmic line of best fit is computed where y is the RSSI value at negative peak and x is sampling rate.

As different human subject may attenuate the RSSI readings differently, negative peak can be a unique radio frequency signature profiling parameter of a human subject. However, from the value of negative peaks obtained from the experiment, it is observed that the negative peak of one human subject is not constant over different sampling rate. There may be different causes to the reading differences such as the movement pace of human subject while walking across the LoS. A slower pace affects the RSSI readings more compared to a faster pace [13-15].

4. CONCLUSIONS

In conclusion, the characteristic analysis of RSSI readings using ESP8266 WiFi serial transceiver module has been executed and presented in this paper. Two aspects are discussed which are the effect of obstruction at LoS and the effect of sampling rate and human crossing. Each aspect is investigated under different experimental setups.RSSI readings are heavily affected by obstruction at the LoS between a transmitter and receiver.Therefore, if RSSI is to be used for distance-related implementation, an extensive research is needed to develop a sophisticated algorithm to overcome the effect of obstructions in RSSI readings.Looking at it in another perspective, the effect of obstruction on RSSI readings can be beneficial subjected to a proper implementation such as distinguishing different thickness of a material. There is no significant effect of sampling rate on RSSI readings. However, human crossing at the LoS between a transmitter and receiver attenuates RSSI readings significantly due to shadowing effect. In addition, the use of negative peak value resulted from human crossing can be utilized as a unique radio frequency signature profiling parameter of a human subject. An extensive research on developing a robust radio frequency human signature profiling algorithm using RSSI readings is highly favored. Furthermore, theinvention can be implemented in human presence detection and identification system that can be used for multiple purposes which bring positive impact in the security and Internet of Things' technological advancements.

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BIOGRAPHIES OF AUTHORS

Rafhanah Shazwani Rosli is a Graduate Research Assistant at the department of Electrical and Computer Engineering, International Islamic University Malaysia (IIUM). She obtained her Bachelor of Engineering in Electronic – Computer & Information from International Islamic University Malaysia in 2016. She is currently doing her Master of Science in Computer & Information Engineering at International Islamic University Malaysia. Hercurrent research are in the domain of Internet of Things.

Mohamed H. Habaebi (M'99–SM'16) received his first degree from the Civil Aviation and Meteorology High Institute (CAHI), Libya ('91), his MSc in Electrical Engineering from Universiti Teknologi Malaysia ('94), and his Ph.D. in Computer and Communication System Engineering from Universiti Putra Malaysia ('01). He is currently an Associate Professor and the Post Graduate Academic Advisor at the Department of Electrical and Computer Engineering, International Islamic University Malaysia. He heads the research works on Internet of Things at the department. He has supervised many Ph.D. and M.Sc. students, published more 120 articles and papers and sits on editorial board of many international journals. He is actively publishing in M2M communication protocols, wireless sensor and actuator networks, cognitive radio, small antenna system & radio propagation and wireless communications & network performance evaluation. He is an active member of IEEE and an active reviewer to many international journals.

Md Rafiqul Islam (M'02) received his Bachelor of Science in Electrical and Electronic Engineering from Bangladesh University of Engineering & Technology (BUET), Dhaka in 1987. He received his MSc and PhD both in Electrical Engineering from University of Technology Malaysia in 1996 and 2000 respectively. He is currently working as a professor in the Department of Electrical and Computer Engineering, Faculty of Engineering, International Islamic University Malaysia. He has supervised more than 50 PhD and MSc students and has published more than 200 research papers in international journals and conferences. His areas of research interest are wireless channel modeling, radio link design, RF propagation measurement and modeling in tropical and desert, RF design, smart antennas and array antennas design, FSO propagation and modeling etc. He is a Life Fellow of Institute of Engineers Bangladesh and member of IEEE and IET.